THE SPIN STRUCTURE OF NUCLEONS AND DEEP INELASTIC SCATTERINGS *

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Abstract

Based on a simple model which is compatible with the idea of the static quark model and the parton model, the polarized structure functions of proton and deuteron, two-spin asymmetries of π^0 in polarized pp reactions and inelastic J/ψ productions in polarized lepton-proton collisions are analyzed. In particular, an important role of polarized gluon distributions is pointed out.

1. Introduction

The advent of so-called "the proton spin crisis" which has emerged from the measurement of $g_1^p(x)$ by the EMC Collaboration[1], has stimulated a great theoretical and experimental activity in particle physics[2]. So far various theoretical approaches have been provided to get rid of the crisis. Although some of them are very successful, a lot of problems remain to be solved. The problem is still very challenging topics in particle physics. In this Talk, after briefly reviewing what the problem is, I would like to discuss the physics of spin effects in various processes from a rather conservative point of view, *i.e.* based on a simple model which is compatible with the idea of the naive quark model and parton model. Furthermore, polarized gluon distributions are examined in detail.

2. Proton spin problem

In the kinematical region where the one-photon exchange is dominant, the differential cross section of the deep inelastic lepton-nucleon scattering, $\ell + N \to \ell' + X$, is given by the product of the lepton tensor $L^{\mu\nu}$ and the hadron tensor $W_{\mu\nu}$. The antisymmetric part of $W_{\mu\nu}$ under $\mu \leftrightarrow \nu$ is described as

$$W_{\mu\nu}^{(A)} = \epsilon_{\mu\nu\rho\sigma} q^{\rho} \left[s^{\sigma} \left\{ M_N G_1(\nu, q^2) + \frac{p \cdot q}{M_N} G_2(\nu, q^2) \right\} - s \cdot q p^{\sigma} \frac{G_2(\nu, q^2)}{M_N} \right] , \tag{1}$$

where $G_{1,2}$ are called the spin-dependent structure functions. In terms of $G_{1,2}$, the difference of differential cross sections $d\sigma_{\uparrow\uparrow}$ and $d\sigma_{\uparrow\downarrow}$, where the helicities of the longitudinally polarized

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beam and target are parallel and antiparallel, respectively, can be written as

$$\frac{d^2 \Delta \sigma}{d\Omega dE'} = \frac{4\alpha^2 E'}{EQ^2} \left\{ (E + E' \cos \theta) M_N G_1(\nu, Q^2) - Q^2 G_2(\nu, Q^2) \right\} , \qquad (2)$$

where θ is the lepton scattering angle in the lab. frame, and E and E' are the initial and final lepton energies, respectively. G_2 in eq.(2) is suppressed with respect to G_1 by a factor $\frac{Q^2}{EM_N} \sim 0.01$, for a typical beam energy of 100 GeV. In the region of deep inelastic scattering(DIS), $G_{1,2}$ have a scaling property(Bjorken scaling);

$$M_N^2 \nu G_1(\nu, Q^2) \to g_1(x) , \qquad M_N \nu^2 G_2(\nu, Q^2) \to g_2(x) ,$$
 (3)

where $x = \frac{Q^2}{2M_N \nu}$ is a dimensionless scaling variable. The Bjorken scaling has been understood well by the parton model: the DIS is viewed as an incoherent sum of elastic scatterings of leptons by pointlike constituents inside a nucleon. According to the parton model, $g_1(x)$ is described as

$$g_1(x) = \frac{1}{2} \sum_{i} e_i^2 \left\{ q_{i\uparrow}(x) - q_{i\downarrow}(x) + \bar{q}_{i\uparrow}(x) - \bar{q}_{i\downarrow}(x) \right\} \equiv \frac{1}{2} \sum_{i} e_i^2 \delta q_i(x) , \qquad (4)$$

where the sum is taken over the various species of partons with charge e_i (i=u, d, s, c, ···). $q_{i\uparrow}(x)$ ($q_{i\downarrow}(x)$) represents the parton distribution polarized in parallel (antiparallel) to the nucleon spin with the momentum fraction x of the nucleon. It is well known that the Bjorken scaling is violated even at large Q^2 . Tis is due to anomalous dimensions of the flavor singlet composite operators appearing in the operator product expansion of the electromagnetic current and running of the strong coupling constant α_S . Perturbative QCD describes well such scaling violations.

In 1988, EMC group reported[1]

$$\int_{0}^{1} g_{1}^{p}(x, Q^{2}) dx = \frac{1}{2} \int_{0}^{1} \left\{ \frac{4}{9} \delta u(x, Q^{2}) + \frac{1}{9} \delta d(x, Q^{2}) + \frac{1}{9} \delta s(x, Q^{2}) \right\} dx$$

$$= \frac{1}{2} \left\{ \frac{4}{9} \Delta u(Q^{2}) + \frac{1}{9} \Delta d(Q^{2}) + \frac{1}{9} \Delta s(Q^{2}) \right\}$$

$$= 0.126 \pm 0.010(stat.) \pm 0.015(syst.) . \tag{6}$$

at $Q^2=10.7~{\rm GeV^2}$, where $\frac{1}{2}\Delta q_i(Q^2)=\frac{1}{2}\int_0^1\delta q_i(x,Q^2)dx$ means the spin carried by quark i in the proton. By combining the data on neutron β decays, $\Delta u-\Delta d=F+D=1.259\pm0.006$ [3] and hyperons β decays, $\Delta u+\Delta d-2\Delta s=3F-D=0.688\pm0.035$ [4], they obtained $\frac{1}{2}\Delta u=0.391\pm0.016\pm0.023$, $\frac{1}{2}\Delta d=-0.236\pm0.016\pm0.023$ and $\frac{1}{2}\Delta s=-0.095\pm0.016\pm0.023$. Then the sum of the quark spin contributions to the proton becomes

$$\frac{1}{2}\Delta\Sigma = \frac{1}{2}\sum_{i}\Delta q_{i} = \frac{1}{2}\left\{\Delta u + \Delta d + \Delta s\right\}$$

$$= 0.060 \pm 0.047 \pm 0.069 . \tag{7}$$

This implies that very little of the proton spin is carried by quarks. Furthermore, the rather large Δs is surprising. The results are very different from the prediction by the static quark

model and also the Ellis-Jaffe sum rule[5] derived from current algebra and the assumption of $\Delta s = 0$. It is called "proton spin crisis". † So far a number of ideas have been proposed to get rid of the crisis. Among them, there has been an interesting idea that gluons contribute significantly to the proton spin through the $U_A(1)$ anomaly of QCD[7]. In this model, spin-dependent quark distributions are largely affected by gluons and the amount of the proton spin carried by quarks is not necessarily small, where the integrated value of the polarized gluons $(\Delta G(Q^2))$ in the proton becomes $5 \sim 6$ at $Q^2 = 10.7 GeV^2$. In the next section, to get into deeper understanding of the problem, I propose a different but simple model which is based on rather conventional idea.

3. Model of spin-dependent distribution functions

In the quark-parton model a proton is composed of three valence quarks accompanied by sea quarks and gluons, though it consists of three constituent quarks alone in the static quark model. As a working model of a proton which is compatible with these pictures, we propose a new wavefunction of a proton described by a superposition of three-, five-, \cdots , body wavefunctions of quarks. In practice, \dot{a} la Carlitz and Kaur[8] we consider that a proton is composed of an active quark interacting with virtual photon in ℓp reactions and a remaining "core". Then, a polarized proton wavefunction is given by [9]

$$|p\uparrow\rangle = a_0 \left[|\Psi_0\rangle + |\Psi_1\rangle \right]_V + a_1 \left[|\Psi'_0\rangle + |\Psi'_1\rangle + \frac{\epsilon}{\sqrt{2}} (|\Psi''_0\rangle + |\Psi''_1\rangle + |\Psi''_{\frac{1}{2}}\rangle) \right]_{V+S} + \cdots,$$
(8)

where V and V+S mean that the constituents are valence quarks, $u_V u_V d_V$, and valence plus sea quarks, $u_V u_V d_V q_S \overline{q}_S$, respectively. The suffix of Ψ, Ψ' and Ψ'' represents the isospin of the "core", which is composed of qq for Ψ and $qqqq/qqq\overline{q}$ for Ψ' and Ψ'' . $|\Psi'_0\rangle$ and $|\Psi'_1\rangle$ are constructed by $uudu\overline{u}$ and $uudd\overline{d}$. Each $|\Psi''_i\rangle$ in the ϵ term comes from $uuds\overline{s}$. $a_0(a_1)$ is the weight of the three- (five-) quark wavefunction. ϵ denotes the relative weight of an s-quark pair to u/d-quark pairs. The values of a_0^2, a_1^2 and ϵ^2 are determined to be 1, 0.1425 and 0.5, respectively, so as to reproduce the magnetic moment[3] and the K/π production ratio in hadron collisions[10].

Then, the spin-dependent distribution functions of quarks can be derived as follows[9]:

$$-\frac{2}{3}d_{V}(x)\} + a_{1}^{2}\left\{\frac{17}{12}u_{V}(x) - \frac{5}{4}d_{V}(x)\right\} + \frac{17}{6}\overline{u}_{S}(x) - \frac{5}{2}\overline{d}_{S}(x) + \frac{\epsilon^{2}}{2}u_{V}(x) - \frac{\epsilon^{2}}{2}\frac{2}{3}d_{V}(x)\}\right],$$

$$\delta d(x) = \widehat{D_{f}}(x)\left[a_{0}^{2}\left\{-\frac{1}{3}d_{V}(x)\right\} + a_{1}^{2}\left\{\frac{7}{12}u_{V}(x) - \frac{3}{4}d_{V}(x)\right\}\right],$$

$$+ \frac{7}{6}\overline{u}_{S}(x) - \frac{3}{2}\overline{d}_{S}(x) - \frac{\epsilon^{2}}{2}\frac{1}{3}d_{V}(x)\}\right],$$

[†]Very recently, SMC group reported a little larger value of the first moment of $g_1^p(x)$, i.e. $\int_0^1 g_1^p(x) dx = 0.136 \pm 0.011(stat.) \pm 0.011(syst.)$ but the main conclusion remains unchanged[6].

$$\delta s(x) = \widehat{D_f}(x) \left[a_1^2 \frac{\epsilon^2}{2} \frac{1}{3} \{ s_S(x) + \overline{s}_S(x) \} \right],$$

with $\widehat{D_f}(x) = \frac{D_f(x)}{a_0^2 + a_1^2 + \frac{\epsilon^2}{2} a_1^2}$, where $D_f(x)$ is called a spin-dilution factor introduced originally in CK model[8] and measures the deviation of spin-dependent distributions from the SU(6) limit. With $a_0 = 1$ and $a_1 = 0$, eq.(9) reduces to CK model as expected. In general, $D_f(x, Q^2)$ can be written by

$$D_f(x, Q^2) = \frac{\{1 - 2P_f(x)\}H_0N(x, Q^2) + 1}{H_0N(x, Q^2) + 1},$$
(10)

where $N(x,Q^2)$ is the density of gluons relative to the quarks and H_0 is fixed to be $H_0=0.0055$ by the Bjorken sum rule[11]. $P_f(x)$ is the probability of the quark spin flip due to interactions between quarks and gluons, and is given as $P_f(x) = \frac{\sigma_{\downarrow\uparrow}(x)}{\sigma_{\uparrow\uparrow}(x) + \sigma_{\downarrow\uparrow}(x)}$ as a function of x by using the analogy of Rutherford scattering[9]. With $P_f(x) = \frac{1}{2}$, eq.(10) results in the one in CK model. By using the Duke-Owens parametrization for spin-independent quark and gluon distribution functions[12], one can calculate the spin-dependent quark distributions. Furthermore, the effect of gluons on the first moment of $g_1^p(x)$ is taken into account through the $U_A(1)$ anomaly . Since at present we have no definite knowledge of the polarized gluon distribution functions, we simply assume $^{\ddagger}(\text{Fig.1})$

$$\delta G(x, Q^2 = 10.7 GeV^2) = Cx^{0.1} (1 - x)^{17}, \tag{11}$$

where C=3.1 is determined so as to fit $\int_0^1 g_1^p(x)dx=0.126(\text{EMC})$. By taking eq.(11), the spin-dependent quark distributions are modified from δq to $\delta q_i(x,Q^2)=\delta q_i(x,Q^2)-\frac{\alpha_S(Q^2)}{2\pi}\delta G(x,Q^2)$. (Fig.1) With the help of the results in Fig.1, we can reproduce the x dependence of $g_1^p(x,Q_{EMC}^2)$ [1] and $g_1^d(x,Q_{SMC}^2)$ [14] (Figs.2 and 3). Moreover, the model leads to $\Delta u=1.002, \Delta d=-0.256, \Delta s=0.019$ and hence $\frac{1}{2}\{\Delta u+\Delta d+\Delta s\}=0.382$, that is, 76% of the proton spin is to be carried by quarks. Note that the model predicts rather small Δs . Owing to this small Δs , the $U_A(1)$ anomaly inevitably leads to large gluon polarizations ($\Delta G=6.32$) in order to explain the EMC data. However, is the gluon polarization really so large in the proton? To confirm this result, it is absolutely necessary to measure, in experiment, the physical quantity sensitive to polarized gluon distributions. In the following section, gluon polarization effects on various reactions are studied.

4. Way to probe polarized gluon distributions

In this section, we are concentrated on two interesting processes which give us important informations on the polarized gluons: one is the π^0 production in polarized proton-polarized proton collisions and the other is the J/ψ production in polarized electron-polarized proton collisions. Before getting into the discussion of these processes, I present some typical examples of polarized gluon distributions considered here:

(a) the present model;

$$x\delta G(x, Q^2 = 10.7 \text{GeV}^2) = 3.1x^{0.1}(1-x)^{17} \text{ with } \Delta G(Q_{EMC}^2) = 6.32,$$
 (12)

 $^{^{\}ddagger}$ In practice, eq.(11) has been taken under some theoretical considerations and numerical analyses[13].

(b) Cheng-Lai type model[15];

$$x\delta G(x, Q^2 = 10 \text{GeV}^2) = 3.34 x^{0.31} (1-x)^{5.06} (1-0.177x)$$

with $\Delta G(Q_{EMC}^2) = 5.64$, (13)

(c) BBS model[16];

$$x\delta G(x, Q^2 = 4\text{GeV}^2) = 0.281 \left\{ (1-x)^4 - (1-x)^6 \right\} + 1.1739 \left\{ (1-x)^5 - (1-x)^7 \right\}$$

with $\Delta G(Q_{EMC}^2) = 0.53$, (14)

(d) no gluon polarization model;

$$x\delta G(x, Q^2 = 10 \text{GeV}^2) = 0 \text{ with } \Delta G(Q_{EMC}^2) = 0.$$
 (15)

Among these examples, ΔG of types (a) and (b) are large while those of types (c) and (d) are small and zero, respectively. The x dependence of $x\delta G(x,Q^2)$ and $\delta G(x,Q^2)/G(x,Q^2)$ which are evolved up to $Q^2=10.7~{\rm GeV^2}$ by the Altarelli–Parisi equations are depicted in Fig.4 (A) and (B), respectively. As for the $x\delta G(x,Q^2)$ with large ΔG , many people[17] have taken up so far the one similar to type (b). As shown in Fig.4, the $x\delta G(x)$ of type (b) has a peak at $x\approx 0.05$ and gradually decreases with increasing x while that of (a) has a sharp peak at x<0.01 and rapidly decreases. The type (c) which is derived from the requirements of the color coherence at $x\sim 0$ and the counting rule at $x\sim 1$ has no sharp peak but distributes rather broadly.

4. 1. Two-spin asymmetry for π^0 productions in polarized pp collisions

The interesting physical parameter to be discussed here is the two-spin asymmetry A_{LL} as a function of transverse momenta p_T of produced particles like π^0 , γ and J/ψ . A_{LL} is defined as

$$A_{LL} = \frac{\left[d\sigma_{\uparrow\uparrow} - d\sigma_{\uparrow\downarrow} + d\sigma_{\downarrow\downarrow} - d\sigma_{\downarrow\uparrow}\right]}{\left[d\sigma_{\uparrow\uparrow} + d\sigma_{\uparrow\downarrow} + d\sigma_{\downarrow\downarrow} + d\sigma_{\downarrow\uparrow}\right]}$$
$$= \frac{Ed\Delta\sigma/d^3p}{Ed\sigma/d^3p}, \tag{16}$$

where $d\sigma_{\uparrow\downarrow}$, for instance, denotes that the helicity of a beam particle is positive and that of a target particle is negative. So far, A_{LL} for only inclusive π^0 -production has been measured by the E581/704 Collaboration at Fermilab[18] by using longitudinally polarized proton (antiproton) beams and longitudinally polarized proton targets. Two–spin asymmetries $A_{LL}^{\pi^0}(\stackrel{(}{p}p)$ contain contributions of various subprocesses. The difference between $A_{LL}^{\pi^0}(pp)$ and $A_{LL}^{\pi^0}(pp)$ for theoretical calculations is due to the magnitude and sign of contributing subprocesses to pp and pp reactions. For subprocesses concerned here, an incident pq is a sea component for a proton while it is a valence component for an antiproton. Hence, $qq \to qq$, $qq \to gg$ and

 $\overline{q}g \to \overline{q}g$ contribute more to $\overline{p}p$ than to pp reactions. On the other hand, $qq \to qq$ and $qg \to qg$ contribute more to pp than to $\overline{p}p$ reactions. Furthermore, the spin–dependent subprocess cross section $d\Delta\hat{\sigma}/d\hat{t}$ is negative for $q_i\overline{q}_i \to \overline{q}_iq_i$, $q_i\overline{q}_i \to q_j\overline{q}_j/\overline{q}_jq_j$, $q_i\overline{q}_i \to gg$ and $gg \to q_i\overline{q}_i$, while it is positive for other subprocesses. Therefore, the spin–dependent differential cross section $Ed\Delta\sigma/d^3p$ for $\overline{p}p$ reactions becomes a little smaller than the one for pp reactions. This leads to smaller $A_{LL}^{\pi^0}(\overline{p}p)$ than $A_{LL}^{\pi^0}(pp)$ as shown in Figs.5 and 6. Several people have analyzed these interesting data[19]. By comparing the data with the calculations by Ramsey and Sivers[19], the E581/704 group has concluded that the large ΔG in the proton is ruled out[18].

Here by using the spin–dependent gluon distribution functions ((a)~(d)) presented above, we have calculated $A_{LL}^{\pi^0}(pp)$ and $A_{LL}^{\pi^0}(\overline{p}p)$, which are shown in Figs.5 and 6 for $\sqrt{s}=20$ GeV and $\theta=90^\circ$, respectively, where we typically choose $Q^2=4p_T^2$ with the transverse momentum p_T of π^0 . Comparing theoretical predictions with the experimental data, one can see that not only the no gluon polarization model (type (d)) but also the present model (type (a)) seem to be consistent with the experimental data for both pp and $\overline{p}p$ collisions. It is remarkable to see that type (a) works well in spite of large ΔG . Owing to the kinematical constraint of x in the hard–scattering parton model, the contributions from 0 < x < 0.05 to $A_{LL}^{\pi^0}(\stackrel{\cdot}{p}p)$ are vanishing. Accordingly, there are no significant contributions from the spin–dependent gluon distribution of type (a) to $A_{LL}^{\pi^0}$ though $\Delta G(Q^2)$ for this case is quite large. However, if we take the polarized gluon distribution $x\delta G(x)$ of type (b) which is still large for x>0.05, we have a significant contribution from the large $x\delta G(x)$ to $A_{LL}^{\pi^0}$ and then the result becomes inconsistent with the E581/704 data. Furthermore, if the value of $x\delta G(x)$ is not very small for x>0.15 even though $\Delta G(x)$ is small (as in the case of type (c)), the calculation might not agree with the experimental data. Therefore, one can conclude that a large gluon polarization inside a proton is not necessarily ruled out but the shape of the spin–dependent gluon distribution function is strongly constrained by the E581/704 data.

4. 2. J/ψ productions in polarized lp collisions

As can be seen from the above analyses, one cannot distinguish types (a) and (d) of $x\delta G$, as long as we remain in the analysis on $A_{LL}^{\pi^0}$. Here, to see more clearly the effect of the spin–dependent gluon distributions, we study the J/ψ production processes in polarized ℓp collisions, which may serve as the most straightforward method for extracting $\delta G[20,21]$. The difference of types (a) and (d) can be found from the analysis of inelastic J/ψ productions in polarized ep collisions[21]. In the inelastic region where the J/ψ particles are produced via the photon–gluon fusion, $\gamma^* g \to J/\psi g$, the spin–dependent differential cross section is given by

$$\frac{d\Delta\sigma}{dx} = x\delta G(x, Q^2)\delta f(x, x_{min}) , \qquad (17)$$

where $\delta G(x, Q^2)$ is the spin-dependent gluon distribution function and x the fraction of the proton momentum carried by the initial state gluon. δf is a function which is sharply peaked at x just above x_{min} and given by [21]

$$\delta f(x, x_{min}) = \frac{16\pi\alpha_S^2 \Gamma_{ee}}{3\alpha m_{J/\psi}^3} \frac{x_{min}^2}{x^2}$$
(18)

$$\times \left[\frac{x - x_{min}}{(x + x_{min})^2} + \frac{2x_{min}x \ln \frac{x}{x_{min}}}{(x + x_{min})^3} - \frac{x + x_{min}}{x(x - x_{min})} + \frac{2x_{min} \ln \frac{x}{x_{min}}}{(x - x_{min})^2} \right] ,$$

where $x_{min} \equiv m_{J/\psi}^2/s_T$ and $\sqrt{s_T}$ is the total energy in photon–proton collisions. Fig.7 shows the x dependence of $d\Delta\sigma/dx$ calculated with types of (a) and (b) for various energies including relevant HERA energies. As δf has a sharp peak, the observed cross section $d\Delta\sigma/dx$ directly reflects the spin–dependent gluon distribution near x_{peak} . As is seen from eq.(17), $d\Delta\sigma/dx$ is linearly dependent on the spin–dependent gluon distribution. Thus, if $\delta G(x)$ is small or vanishing, $d\Delta\sigma/dx$ must be necessarily small. We are eager for the result given in Fig.7 being checked in the forthcoming experiments.

5. Discussion

Before closing this Talk, I would like to give some comments on the remaining problems. One comment is on the polarized s quarks. The EMC data suggest a large and negative contribution of s quarks to the proton spin, $\Delta s = -0.19$. However, contrary to such a large Δs , the experimental data on charm productions in neutrino DIS gave a restrictive bound $|\Delta s| \leq 0.057^{+0.023}_{-0.057}[22]$ which is in little agreement with the EMC results. A way to get rid of this inconsistency might come from the $U_A(1)$ anomaly. If the $U_A(1)$ anomaly is taken into consideration and Δs from the EMC data is replaced by Δs , then these data might be reconciled with each other by taking rather large ΔG . To confirm this interpretation, one need to measure independently the magnitude of both the polarized gluons and strange quarks.

Another comment is on the proton spin sum rule, $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_Z \rangle_{q+G}$. If ΔG is large ($\simeq 5 \sim 6$), we are to have an approximate relation $\langle L_Z \rangle_{q+G} \simeq -\Delta G$. However, at present nobody knows the underlying physics of what it means. It remains to be a problem, though the idea of the $U_A(1)$ anomaly is attractive.

The running and future experiments on spin physics by deep inelastic scattrings are decisively important for going beyond the present understanding on the hadron structure.

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- Fig. 1 : Modified spin–dependent distribution functions of quarks and the spin–dependent distribution function of gluons at $Q^2 = 10.7 \text{ GeV}^2$.

- Fig. 2: Comparison of the spin–dependent structure function $xg_1^p(x,Q^2=10.7 \text{ GeV}^2)$ with experimental data. The solid and the dashed lines denote the result of the present model and the EMC fit, respectively. The full circle, open triangle and square points show the EMC, SLAC (E80) and SLAC(E130) data, respectively. Inner and outer error bars mean the statistical and total errors, respectively
- Fig. 3 : The x dependence of the spin– dependent deuteron structure function $xg_1^d(x,Q^2)$ at $Q^2=4.6~{\rm GeV^2}$. Experimental data are taken from[14].
- Fig. 4 : The x dependence of (A) $x\delta G(x,Q^2)$ and (B) $\delta G(x,Q^2)/G(x,Q^2)$ for various types (a)–(d) given by eqs.(12), (13), (14) and (15) at $Q^2=10.7~{\rm GeV^2}$.
- Fig. 5: Two–spin asymmetry $A_{LL}^{\pi^0}(pp)$ for $\sqrt{s}=20$ GeV and $\theta=90^\circ$, calculated with various types of $x\delta G(x)$, as a function of transverse momenta p_T of π^0 . The solid, dashed, small–dashed and dash–dot- ted lines indicate the results using types (a), (b), (c) and (d) in eqs.(12), (13), (14) and (15), respectively. Experimental data are taken from [18].

Fig. 6: Two–spin asymmetry $A_{LL}^{\pi^0}(\overline{p}p)$ for $\sqrt{s}=20$ GeV and $\theta=90^\circ$, calculated with types (a), (b), (c) and (d) for $x\delta G(x)$, as a function of transverse momenta p_T of π^0 . Data are taken from [18].

Fig. 7: The distribution $d\Delta\sigma/dx$ predicted by using types (a) and (b) of $x\delta G(x,Q^2)$, as a function of x for different values of $\sqrt{s_T}$. The solid (dashed) curve corresponds to type (a) (type (b)).